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WATER BALANCE OF WELLINGTON TANK IRRIGATED WATERSHED USING SCS CURVE NUMBER AND GIS

SRINIVASAN K[1] & POONGOTHAI S[2]

[1]Assistant Professor, Department of Civil Engineering, Annamalai University, Annamalainagar, Tamil Nadu, India

[2]Professor, Department of Civil Engineering, Annamalai University, Annamalainagar, Tamil Nadu, India

ABSTRACT

Runoff is one of the most important hydrological variables used in most of the water resourcesapplications. In this study, estimation of runoff for Wellington Resrvoir is carried out using SCS and GIS techniques. The study area covers an area of 495.3 km2 and physiographically the area is characterized by Western pediplains of entire area covered by Mangalur and Nallur blocks. This area is occupied by denudational landforms like shallow buried pediment, deep buried pediment and pediments. Central part of the district is characterized by sedimentary high grounds, elevation >80 m of Cuddalore sandstone of Tertiary age. This zone occupies part of Virudhachalam, and Kattumannarkoiltaluks. The Soil Conservation Service Curve Number (SCS CN) also known as hydrologic soil group method was used in this study. This method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate result. From the study, monthly as well as annual rainfall and corresponding runoff were estimated.The curve number method, also known as the hydrological soil cover complex method, is a versatile and widely used procedure for runoff estimation. This method includes several important properties of the watershed namely, soils permeability, land use and antecedent soil water conditions which are taken into consideration. In the present study, the runoff from SCS Curve Number model modified has been used byconventional database and GIS for Wellington agricultural watershed in Tittaguditaluk, the Cuddaloredistrict. Tittagudi had a population of 20,734. In this taluk, agriculture area is 823.74 km2 and mean annual rainfall is 1110mm. Black soil is predominant soil type in this area and main occupation of the area is agriculture. The groundwater level of the study area ranges from 2m to 8m bgl (below ground level).The rainfall and land use data were used along with the experimental data of soil classification and infiltration rate for the estimation of the runoff for the study area.

KEYWORDS: Hydrological Soil Group, Landuse and Land Cover, Rainfall, Runoff, SCS-CN and Wellington Reservoir

INTRODUCTION

A watershed is the area covering all the land that contributes runoff water to a common point. It is a natural physiographic or ecological unit composed of interrelated parts and function. Each watershed has definite characteristics such as size, shape, slope, drainage, vegetation, geology, soil, geo-morphology, climate and land use. Watershed management implies proper usage of water to land and other natural resources in a watershed for estimation of runoff which is required for planning, developing and managing the water resources. Runoff is one of the most important hydrologic variables used in most of the water resources applications. Direct measurement of runoff provides excellent and timely data but it is limited in use to the exact location where it was collected. In this study the Soil Conservation Service Curve Number (SCS-CN method) also known as hydrologic method was used. This method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate results. Runoff estimates are based upon the soil types, land-use practices within a basin and the influence of the antecedent soil moisture

conditions. Remote sensing and Geographic Information System (GIS) play a vital role to visualize the prevailing status of water resources of the watershed (Poongothai and Thayumanavan, 2002a) and has become a critical tool in hydrological modeling in view of its capacity to handle large amount of spatial and attribute data. Some of its features such as map overlay and analysis help to derive and aggregate hydrologic parameters from different sources such as soil, land cover and rainfall data (Cheng et. Al 2006; Mahboubeh Ebrahimian et. al 2009). In recent days, an integrated study of runoff modeling using SCS-CN and GIS technique has gained significance for estimation of surface runoff (Amutha et. al 2009; Soulis et. al 2009; Ratika Pradhan et. al 2009, Paul et. al 2012). These works mainly aims the estimation of runoff in watershed using SCS-CN method (SCS, 1972).

Study Area

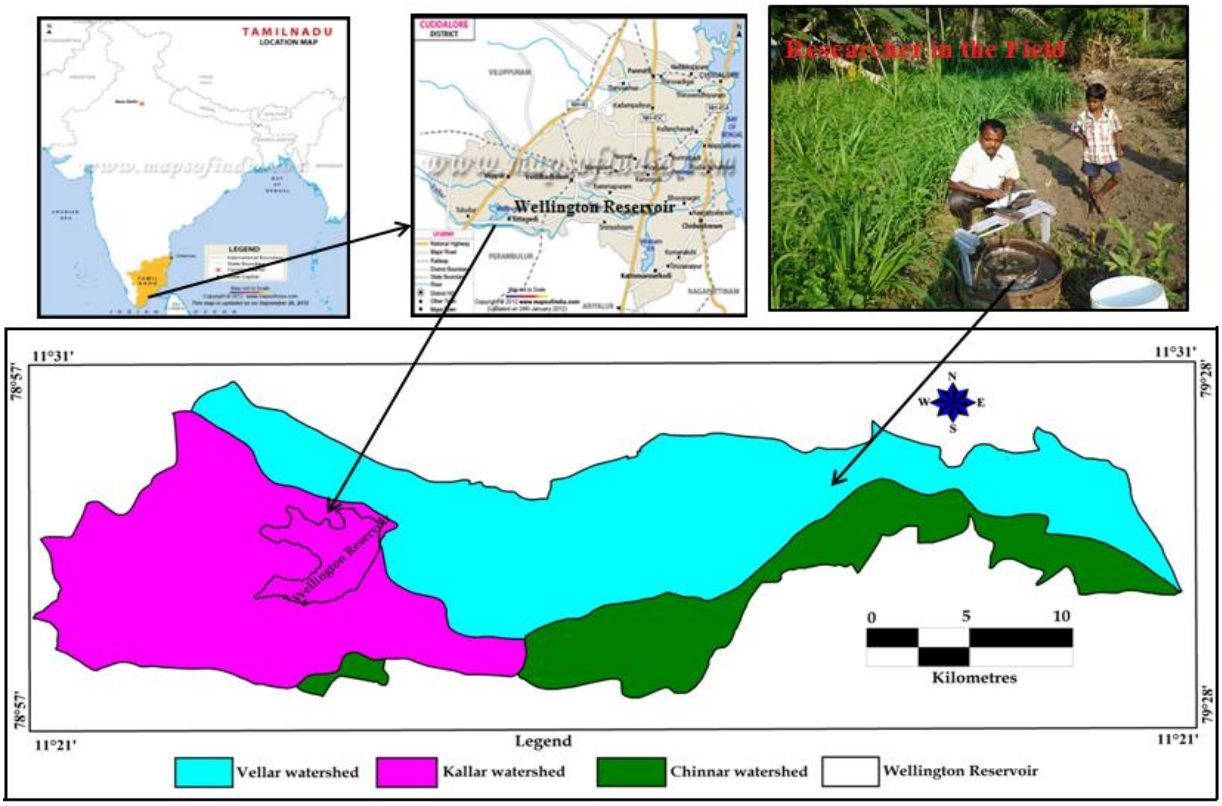

Figure 1: Watershed Map of the Study Area

The study area considered is Wellington reservoir watershed which is located in the Tittakuditaluk. It lies between the longitudes of 11˚21' to 11˚31' E and latitudes of 77˚28' to 77˚57'N (Figure 1). Tittagudi is a panchayat town and taluk headquarter of Cuddalore district, Tamilnadu, India. As of 2001 India Census, Tittagudi had a population of 20,734. In this taluk (Figure 2) agriculture area is 823.74 km^2 and mean annual rainfall is 1110 mm. Black soil is the predominant soil type in this area and main occupation of the area is agriculture.

The groundwater level of the study area ranges from 2 m to 8 m bgl (below ground level). The Reservoir is located in Vellar Basin across a tributary stream PeriyaOdai of Vellar River (Figure 4). It receives Regulated Supply diverted from Vellar River at Tholudur Regulator and an additional catchment area of 129 (km)^2 of its own during North East Monsoon. The Reservoir was constructed during 1913-1923 and irrigates an ayacut of 11,200 Hectare. Paddy, Sugarcane are the major crops grown in and around wellington ayacut. The Reservoir was formed with available earth at site which was not suitable for the formation of Reservoir such formation with nonsuitable soil leads lot of problems such as slips etc., year by year.

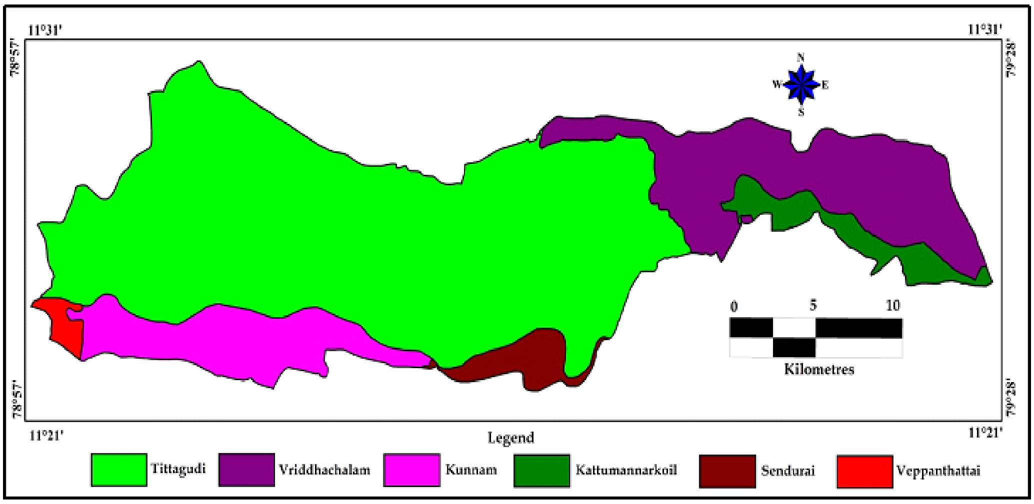

Figure 2: Taluk Map of the Study Area

METHODOLOGY

In this study, Survey of India topographic sheets were used to delineate the watershed boundary, drainage and contour. Remote sensing data of 1:50,000 for delineating land use/land cover map and soil map. Hydrologic soil group map (Figure 2) was prepared according to soil characteristics and type of land use/land cover (Figure 3) for the estimation of runoff from watershed. Daily rainfall data from rain gauge station at Lekkur in TittagudiTaluk for the years 1993 to 2012 (19 years) data were used to calculate the runoff using SCS-CN method.

SCS Curve Number Method

Soil Conservation Service Curve Number (SCS-CN) model is one of the method to estimate surface runoff from watershed. The infiltration losses are combined with surface storage by the relation of

$$\boxed{Q = (P-Ia)^2 / (P-Ia+S)} \qquad (1)$$

Where, Q is the accumulated runoff or rainfall excess in mm, P is the rainfall depth in mm, Ia is the initial abstraction in mm and includes surface storage, interception, and infiltration prior to runoff in the watershed and empirical relation was developed for the term Ia and it is given by,

$$\boxed{Ia = 0.2S} \qquad (2)$$

For Indian condition the term S in the potential maximum retention and it is given by, Where, CN is known as the curve no which can be taken from the handbook of hydrology, section – 4(USDA, 1972). Now the equation 1 can be rewritten as,

$$\boxed{S = (25400/CN) - 254} \qquad (3)$$

$$\boxed{Q = (P-0.3S)^2 / (P+0.7S)} \qquad (4)$$

Knowing the value of CN, the runoff from the watershed was computed from Eq.3 and 4. The CN (dimensionless number ranging from 0 to 100) is determined from a table, based on land cover, antecedent soil moisture condition (AMC) and hydrologic soil group (A, B, C and D), Figure 2 shows the Hydrological Soil Group map prepared by assigning

hydrological soil group based on the infiltration rate. AMC is expressed in three levels (I, II and III), according to rainfall limits for dormant and growing seasons.

HSG and Antecedent Soil Moisture Condition (AMC)

The hydrologic soil group is an attribute of the soil mapping unit. Each soil mapping unit is assigned a particular hydrologic soil group: A, B, C, or D according to the soil's minimum infiltration rate, which is obtained for a bare soil after prolonged wetting (Table 1). Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. The AMC value is intended to reflect the effect of infiltration on both the volume and rate of runoff according to the infiltration curve. The SCS developed three antecedent soil-moisture conditions and labeled them as AMCI, AMCII & AMCIII according to rainfall limits for dormant and growing seasons (Table 1). Prior to estimating runoff for a storm event, the curve numbers was adjusted based on the season and total 5 day antecedent precipitation.

RESULTS AND DISCUSSIONS

Land Use and Land Cover

Four land use and land cover classes were categorized in the watershed as given in Table (6). The land use and land cover map for Wellington watershed is shown in Figure (3).

Soil Classification

According to laboratory soil testing result, the soil of Wellington watershed can be classified into four types; well-graded sand, poorly-graded sand, poor-clay and wellClay distributed at the watershed as shown in Table (2) and Figure (7). The values of curve number for the three antecedent moisture conditions are listed in Table (3).

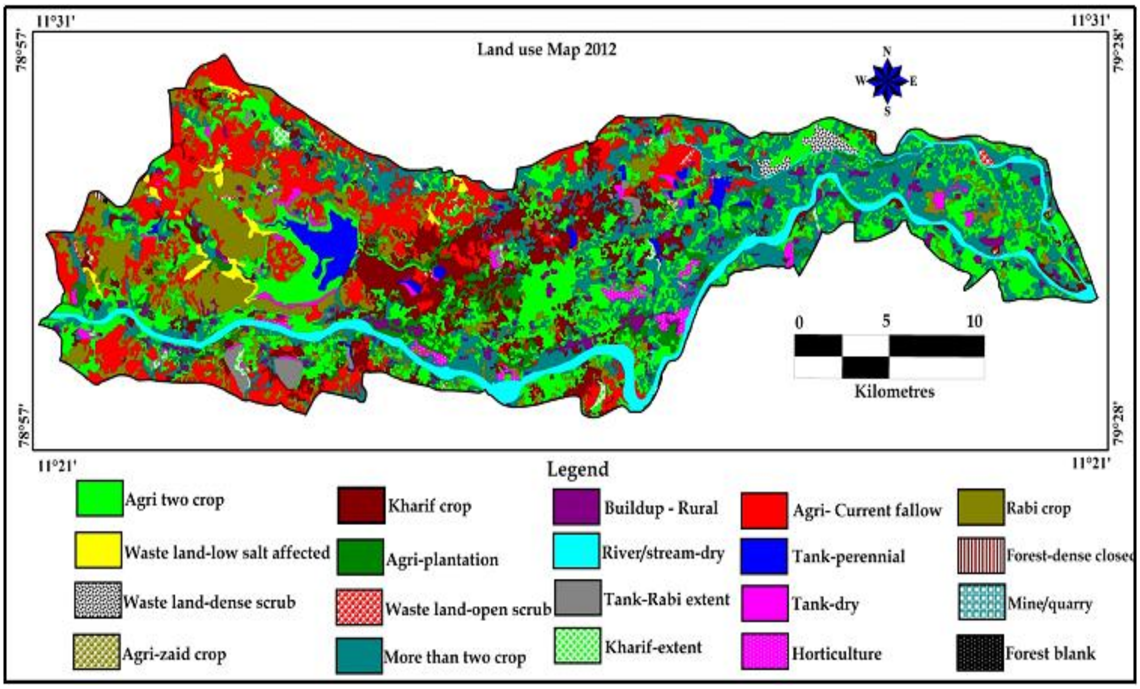

Figure 3: Land Use Map of the Study Area

Table 1: Classification of Antecedent Moisture Conditions

AMC	Total 5 Days Antecedent Rainfall (mm)	
	Dormant Season	Growing Season
I	< 12.7	< 35.6
II	12.7 – 27.9	35.6 – 53.3
III	> 27.9	> 53.3

Table 2: Soil Classification of Study Area

Soil Classification	Area (km^2)	Percentage of Area (%)
Group (A)	47.89	9.67
Group(B)	103.0768	20.81
Group(C)	63.5306	12.83
GroupD)	279.002	56.69
Sum	495.3	100

Table 3: Curve Number for Three Antecedent Moisture Content

AMC	I	II	III
CN	65	82	91

Table 4: Values Used in Hydrological Equation

AMC	CN	S	P > 0.2S
I	65	136.769	27.354
II	82	55.756	11.151
III	91	25.12	5.024

Table 5: The Average Annual Depth and Volume in the Study Area

Years	Total Rainfall (mm)	Total Runoff (mm)	Runoff Percentage	Volume (m^3) Runoff xArea
1993-94	1344	98.112	7.3	48594.89
1994- 95	1239	52.6575	4.25	26081.26
1995- 96	1962	274.68	14	136049
1996- 97	1543	97.209	6.3	48147.62
1997 - 98	1560	176.28	11.3	87311.48
1998 - 99	1395	114.39	8.2	56657.37
1999 -00	1547	122.213	7.9	60532.1
2000 - 01	1343	89.981	6.7	44567.59
2001 - 02	1278	69.012	5.4	34181.64
2002 - 03	936	36.504	3.9	18080.43
2003 - 04	1779	266.85	15	132170.8
2004 - 05	1820	232.96	12.8	115385.1
2005 - 06	1692	213.192	12.6	105594
2006 - 07	1617	221.529	13.7	109723
2007 - 08	2345	398.65	17	197451.4
2008 - 09	468	14.976	3.2	7417.61
2009 - 10	1559	152.782	9.8	75672.92
2010 - 11	1531	160.755	10.5	79621.95
2011 - 12	1086	78.192	7.2	38728.5
Average	**1476**	**151.1**	**93.2**	**74840.47**

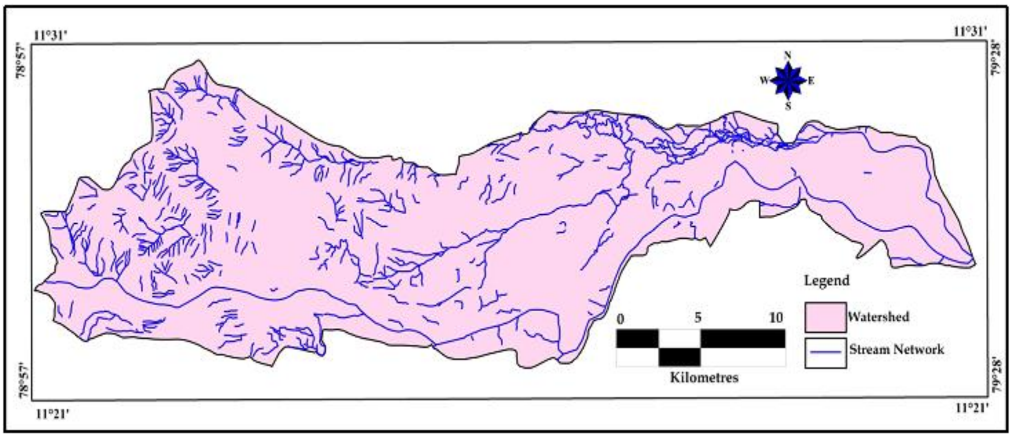

Figure 4: Drainage Map of the Study Area

Table 6: Classes of Land Use/Cover of the Study Area

Land Use	Area (km^2)	Percentage of Area (%)
Crop land	362.5	73.19
Waste land	96.6	19.5
Water bodies	19.7	3.96
Build up land	16.58	3.35
Sum	495.3	100

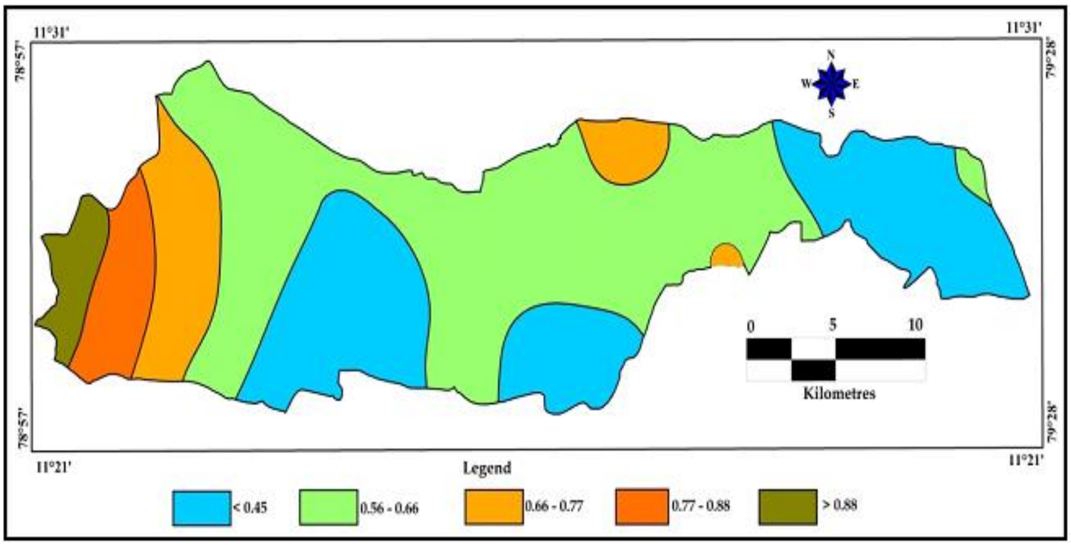

Figure 5: Spatial Distribution of Infiltration Map (cm/hr)

To calculate the surface runoff depth, apply the hydrological equations (3) and (4). These equations depend on the value of rainfall (*P*) and watershed storage (*S*) which calculated from adjusted curve number. Thus, before applying equation (3) the value of (*S*) should be determined for each antecedent moisture condition (AMC) as shown below. There are three conditions: These results are summarized in the Table (4). As a result of the calculations, based on the SCS method, it was found that the average annual surface runoff rate (depth) for the last 20 years in Wellington watershed is equal to 151.1 mm multiple by the area of the watershed (A = 495.3 Sq.km) gives the total average volume of runoff as (74840.47 m^3), which represents 93.2% of the total annual rainfall. The annual rainfall and runoff during (1993-2012) in the study area are shown in Table (5).

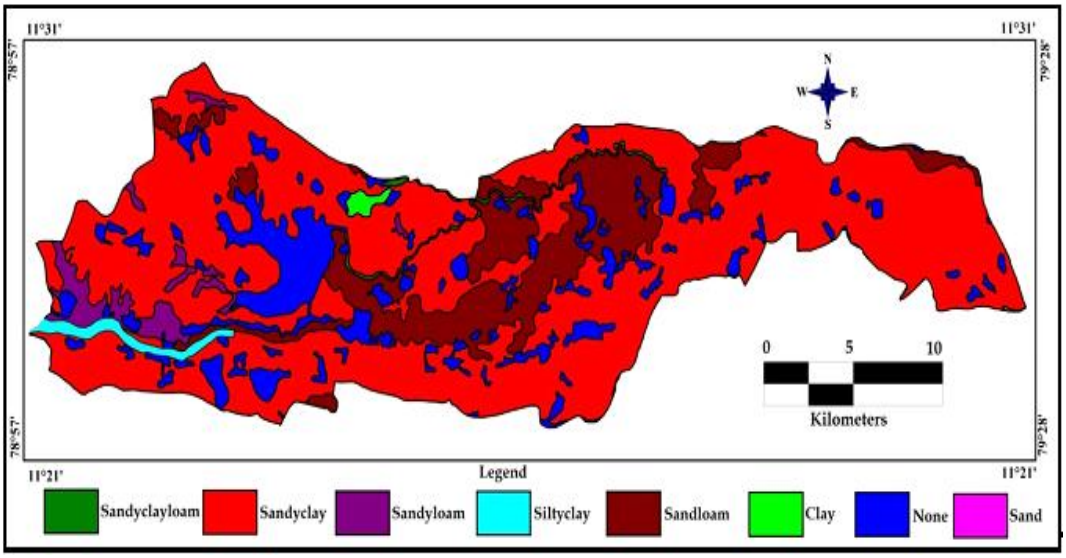

Figure 6: Spatial Distribution of Soil Texture Map

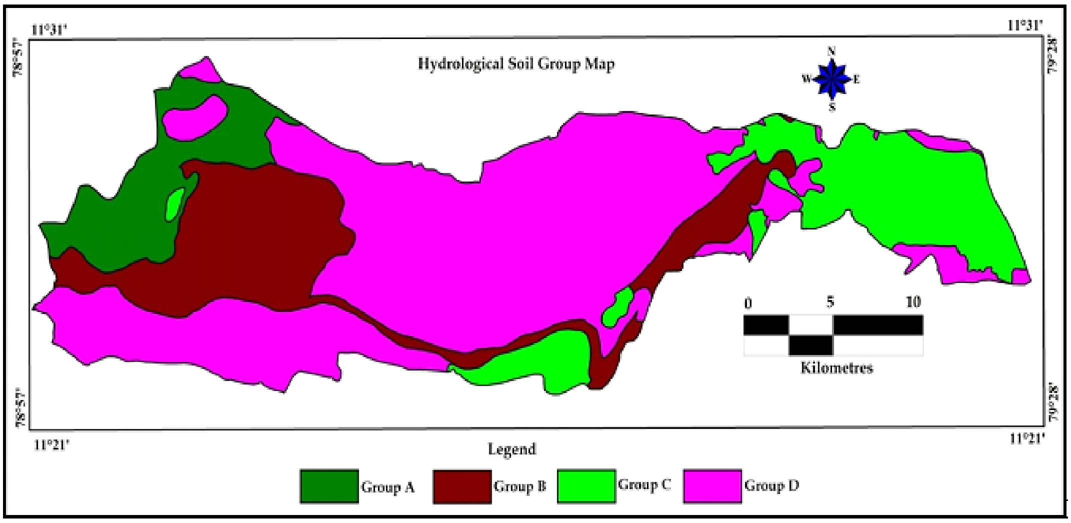

Figure 7: Hydrological Soil Group Map

Providing the Input Information of Rain-Run off Model

The Wellington sub-watershed hydrologic model, to calculate damages and to estimate hydrograph from SCS method. In field visits, the required parameters to develop Rain-Runoff model include qualitative properties, related to the area, soil texture (Figure 6), and the land use and land cover status of the region are measured or estimated.

Infiltration Rate

The measured values of infiltration rates, using a Double Ring Infiltrometer (DRI) at 30 sites covering different land use types, are interpolated in MapInfo 8.5 and the infiltration rate for Wellington watershed is shown in Figure (5).

Estimation of Surface Runoff

By using the data of soil classification and infiltration rates, Wellington watershed was classified into four hydrological soil groups: Group D with infiltration rate (0-0.13) cm/hr, Group C (0.13-0.38) cm/hr, Group B (0.38-0.76) cm/hr and Group A (>7.6) cm/hr based on grade condition of the soil (poorly or well graded). This logical condition is applied in MapInfo, and the hydrologic soil group classification are given in Table (2) and displayed in Figure (7).

$$\boxed{CN = \frac{\Sigma\,(CN_i - A_i)}{A}} \qquad (5)$$

Where, CN = weighted curve number,

CNi = Curve number from 1 to any number N,

Ai = area with cure number CNi

A = The total area of the watershed.

$$\boxed{CN_{(I)} = \frac{(4.2 * CN_{(II)})}{10-(0.058 * CN_{(II)})}} \qquad (6)$$

$$\boxed{CN_{(III)} = \frac{(23 * CN_{(II)})}{10+(0.13 * CN_{(II)})}} \qquad (7)$$

Table 7: Values of Curve Number

Land Use	Hydrologic Soil Group	CN	Area (km^2)	Percentage of Area (%)	Area *CN	Weighted CN of Study Area
1. Crop land	(A)	65	66.76	13.48	4339.4	AMC II= 82 AMC I= 65 AMC III=91
	(B)	77	96.39	19.46	7422.03	
	(C)	84	75.97	15.34	6381.48	
	(D)	88	158.02	31.90	13905.76	
2. Waste land	(A)	78	5.08	1.01	396.24	
	(B)	78	6.34	1.28	494.52	
	(C)	78	6.22	1.26	485.16	
	(D)	78	4.86	1.98	379.08	
3. Water bodies	(A)	100	7.28	1.47	728	
	(B)	100	5.62	1.14	562	
	(C)	100	4.91	1.00	491	
	(D)	100	13.36	2.70	1336	
4. Build up land	(A)	81	7.00	1.41	567	
	(B)	86	13.83	2.79	1189.38	
	(C)	91	13.02	2.63	1184.82	
	(D)	93	10.64	1.15	989.52	
Sum			**495.3**	**100**	**40851. 39**	

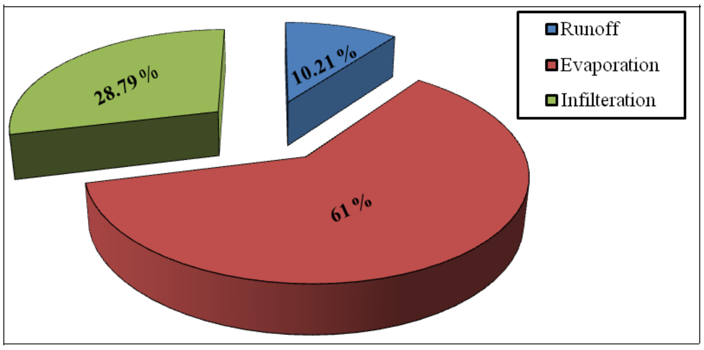

Figure 8: Water Balance of Wellington Reservoir Watershed

The final result in this study determine the water balance parameters of Wellington watershed area whereas the precipitation 1476 mm/year is the main input parameter in the water balance and the average monthly evaporation of the Lekkur station is around 300 mm/month, estimated runoff 151.1 mm and calculated infiltration 424.9 mm are the major output parameters. The results of water budget in the study area are Shown (Figure 8). The yearly highest rainfall and runoff in study area are during the year of 2007 – 08 and lowest rainfall and runoff 2008 – 09 are shown in (Figure 9).

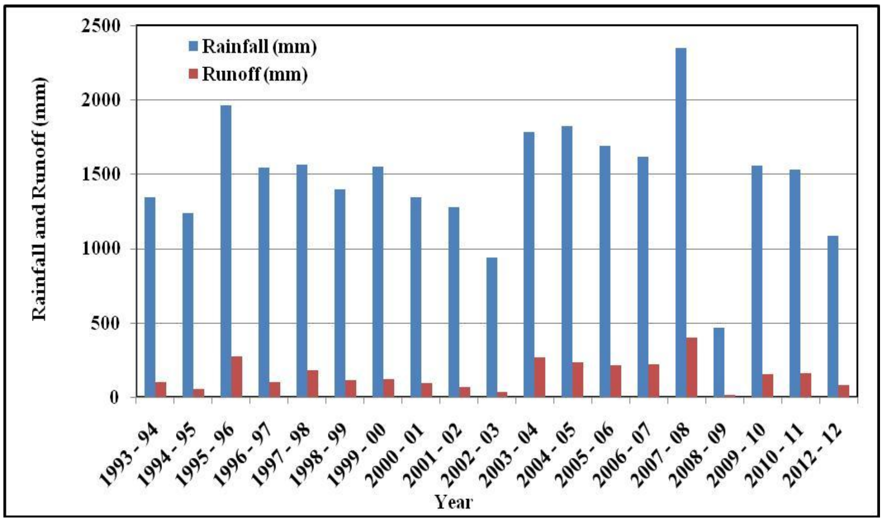

Figure 9: Yearly Rainfall and Runoff

CONCLUSIONS

The results of soil classification, infiltration rates and land use, the study area was classified into four hydrologic soil groups. The composite curve number for normal condition is 82, where for the dry and wet conditions are 65 and 91 respectively. As a result of the calculations, based on the SCS method, it was found that the average annual surface runoff rate (depth) for the last 20 years in Wellington watershed is equal to 151.1 mm multiple by the area of the watershed (A = 495.3 Sq.km) gives the total average volume of runoff as (74840.47 m^3), which represents 93.2% of the total annual rainfall. In the present study, the methodology for determination of runoff for Wellington reservoir using GIS and SCS method was described. This approach could be applied in other watersheds for planning of various conservations measures.

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